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Proposal

for

TERRAIN AVOIDANCE SYSTEM

WESTINGHOUSE ELECTRIC CORPORATION

Air Arm Division

P.O. Box 746 - Baltimore 3, Md.

(Westinghouse reference: AAN-30342A)

22 January 1957

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NOTE: This proposal, Westinghouse reference AAN-30342A incorporates changes from the AAN-30342 version. These changes consist of the addition of this page and a re-write of the following pages: Title page, pages 46, 47 and 48.

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Sanitized Copy Approved for Release 2011/01/10 : CIA-RDP89B00709R000400880017-1

TABLE OF CONTENTS

Sanitized Copy Approved for Release 2011/01/10 : CIA-RDP89B00709R000400880017-1

Sanitized Copy Approved for Release 2011/01/10 : CIA-RDP89B00709R000400880017-1

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LIST OF ILLUSTRATIONS

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I. Scope of Proposal

This proposal covers the essential parameters of a system for detecting natural and man-made obstructions in the flight path of a low altitude high performance aircraft flying at altitudes of 100 to 1500 above the average terrain. The system is designed to operate under all conditions of visibility and to supply the pilot and/or navigator with essential flight path obstruction information required to safely fly at minimum altitude consistent with aircraft capabilities.

II. General Description

A. The Problem

The probability of success of an air mission over enemy territory can be considerably increased by flying at extremely low altitude. This increase in probability of successful mission is due to the increased burden placed on the enemy's radar early warning network when attempting to detect low flying aircraft. The exact minimum altitude which must be flown to preclude detection is a function of both the terrain and the enemy's radar capability. However, in general, the optimum path would be to fly in the valleys below hilltop level, climbing over the hills only when absolutely essential.

When flying under contact (V.F.R.) conditions, the pilot can visually scan the terrain ahead and choose a flight path around most hills. However, under instrument (I.F.R.) conditions, he is forced to fly at a minimum altitude sufficiently high to clear the highest obstruction in the area. Prolonged flight at this altitude assures detection by enemy radar. Therefore, an obstruction warning system for I.F.R. conditions is required which will give the essential information normally available under V.F.R. conditions.

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Sanitized Copy Approved for Release 2011/01/10 : CIA-RDP89B00709R000400880017-1

Figure 1 is a photograph of a flight path terrain clearance indicator presentation obtained during the flight testing phase of Contract AF33(616)2248. Experience has demonstrated that while this type of terrain clearance system does give reliable pull-up information, it does not take advantage of the possibility of flying around obstructions and thus remain in the difficult-to-detect zone. For example: The display illustrated in Figure 1 indicates that a pull-up is in order, however, reference to 1A which is an aerial view of the area clearly shows that a turn-out would be preferable. The pilot could manually position the coverage sector to the right or left of the flight path if desired. However, when added to the burden of flying the aircraft, navigation, etc., this does not seem feasible.

Figure 2 is a drawing of the proposed type of indicator presentation. which combines the flight path (vertical profile) indication with a family of transverse profiles. This type of display will be referred to as the Vertran display. The significant features of this presentation are: (a) the presentation is "natural" in that the pilot is not required to mentally translate the radar data into useful flight data. This reduces reaction time, (b) the information is quantized into specific range segments identified by contrasting colors. This reduces the volume of data presented to the pilot, thus aiding in rapid decisions which are all-important in low altitude flight; and (c) essential turn-out as well as pull-out information is available. This permits the selection of an optimum flight path.

B. Overall System

The proposed system is a refinement of techniques developed and tested since 1952. The design philosophy which will be followed is to select techniques which may be instrumented without resort to critical or complicated

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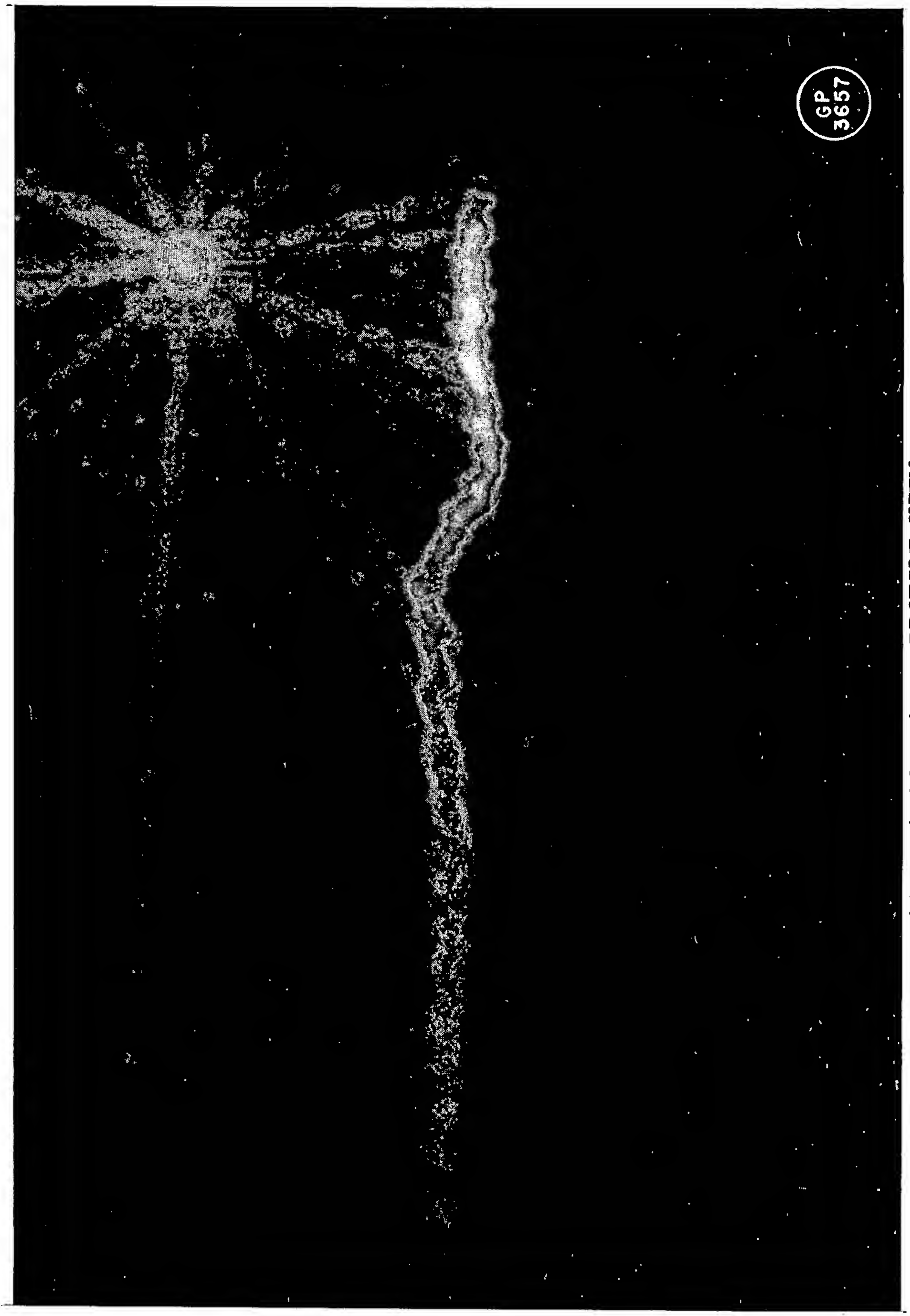

FIG. 1 - MT. MACHENTANGO, PA. - PROFILE VIEW

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FIG. 1A - MT. MACHENTANGO, PA. - AERIAL PHOTOGRAPH

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TYPICAL INDICATOR DISPLAY
THREE DIMENSIONAL RADAR

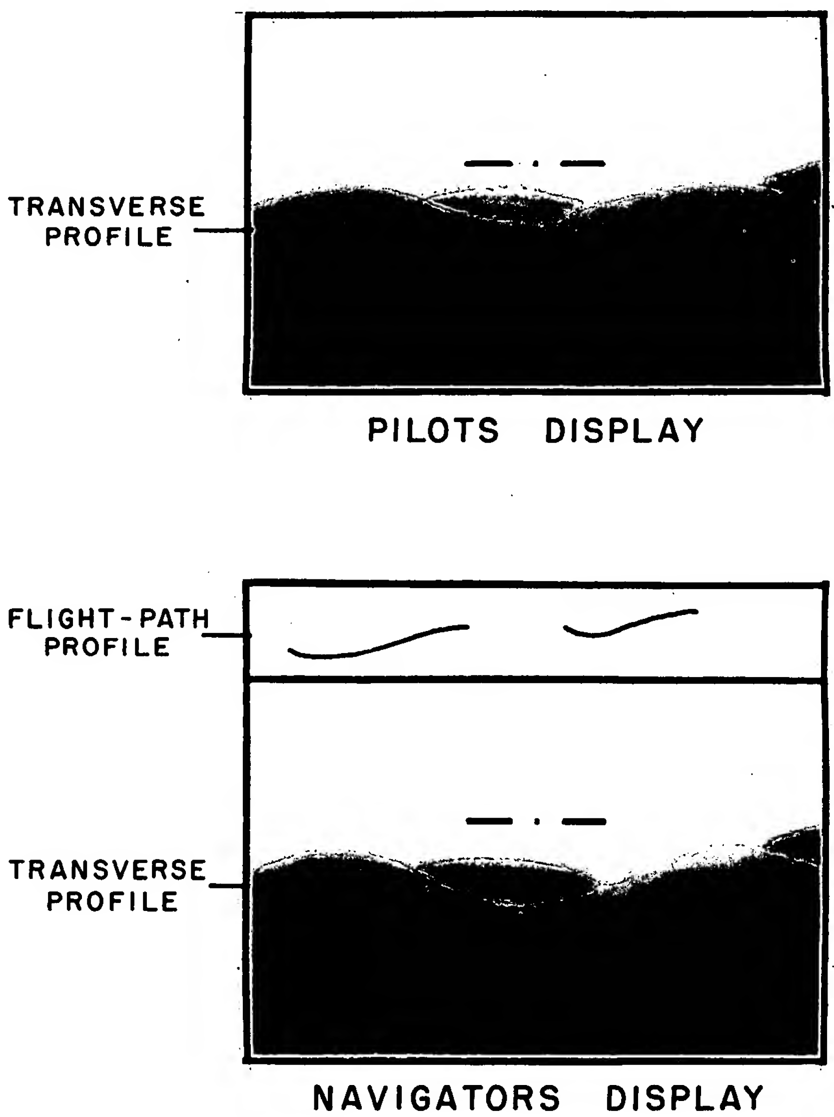

Fig. 2

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circuitry. This approach will improve the overall reliability of the equipment. Individual portions of the radar are covered in considerable detail in later sections of this proposal. A brief resume of the overall system may be had by referring to Figure 3. The transmitted signal is generated in the transmitter unit which consists of a K_a band magnetron modulated by a conventional hydrogen thyratron line type pulser. The 70 kilowatt RF pulse is transmitted by a vertical linear array. The reflected RF energy is picked up by a horizontal linear array. The two antennas are simultaneously scanned to cover a rectangular area forward of the aircraft. The received energy is detected, amplified and range gated in the receiver. The output of the receiver is a series of video pulses separated into separate channels. Each channel represents a specific range segment. The video is displayed on the multicolored cathode ray scope display with a different color being assigned to each specific range segment. This results in a type of three-dimensional display in which azimuth and elevation information is presented on the X and Y axis with range being presented in color. This arrangement presents the operator with transverse profiles of the terrain at discrete ranges forward of the aircraft. Simultaneously, a vertical profile is generated by gating on the vertical profile indicator each time the antenna intersection point crosses the aircraft ground track line. Aircraft position data is also presented on the display to assist the operator in determining his position in relation the obstructions. The system is extremely simple in that the use of separate antennas for transmission and reception eliminates the need for the usual radar duplexing equipment.

The receiver gating circuitry and a considerable portion of the indicator will utilize transistors. Transistors are well suited to this application since all of this circuitry is of the bi-stable variety.

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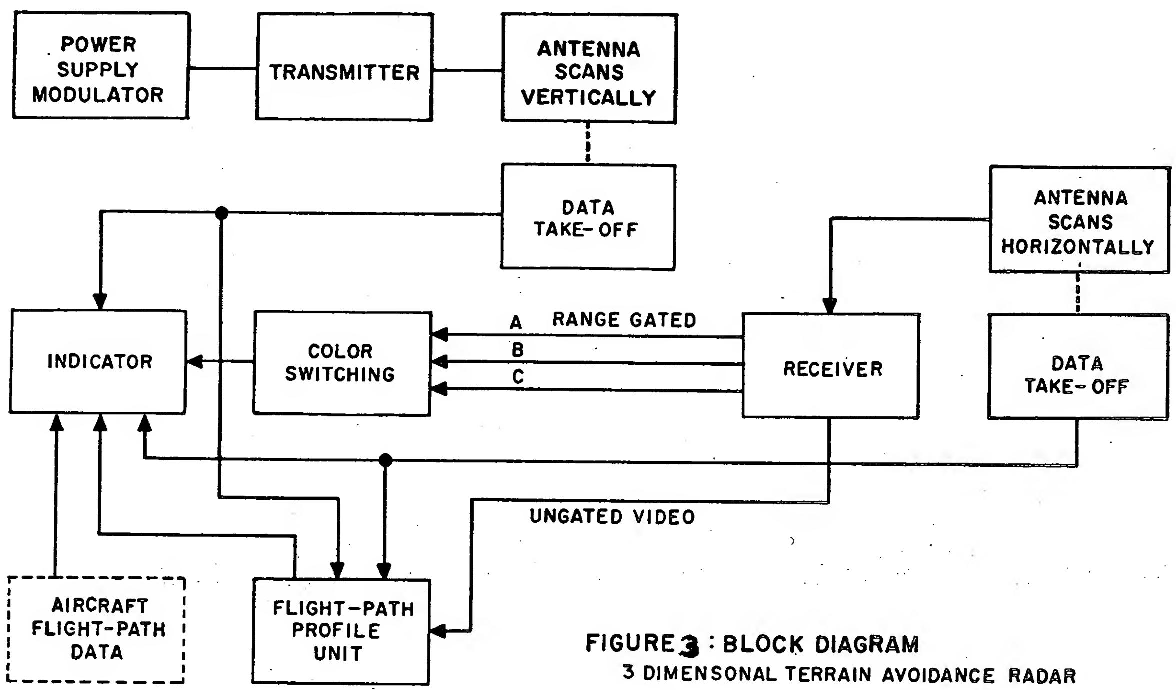

FIGURE 3 : BLOCK DIAGRAM
3 DIMENSONAL TERRAIN AVOIDANCE RADAR

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The antenna installation presents the largest single problem in the system. The use of linear arrays eliminates the need for large nose mounted dishes and in cases where the arrays can be mounted in the leading edges of wings and vertical stabilizers, the antenna problem is very simple. In the case under consideration here, it is not practical to mount the antenna in the wing and stabilizer surface because of interference with the deicing system. The final antenna configuration will be a compromise between radar performance and other factors.

III. System Analysis

A. General

The first month of the program will be devoted to an intensive analysis of all aspects of the system including mission profile and radar parameters.

A considerable quantity of applicable data has been gathered on Contract AF33(616)2248 and AF33(616)3248. This data will be a valuable aid in the selection of the final system parameters. This proposal in Section IV describes one particular system configuration which will perform the terrain avoidance mission. It is obvious that all parameters may be varied with resultant effect on either aircraft and/or radar performance. During the study phase all variables, such as aircraft cruise speed, typical crab angle, angle of attack, flight altitude, maximum climb angle plus all radar parameters, will be evaluated. In the selection of the various parameters the use of a somewhat nebulous quantity which may properly be called a "utility factor" will be introduced. This arises from the near mandate in aircraft systemization that improvement of one function within the vehicle normally requires a compromise in another system or in aircraft performance; and from the obvious fact that variables and alternate approaches do exist in the solution of the terrain

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avoidance phase, which affect reliability and utility of the system. These variables and their practical limits; and the alternate approaches and their relative worth will be carefully considered in arriving at a final system design specification. The "utility factor" will be maximized for highest "safety per pound" consistent with other aircraft system parameters.

B. Specific Considerations

The basic XMA-1 system of terrain avoidance consists of the same basic "black-boxes" so familiar in radar systems, with two notable exceptions apparent in the system block diagram, Fig. 3. These are (1) the presence of separate antennas for the transmitting and receiving functions, and (2) the resultant absence of TR and ATR components in the RF portion. As will be noted in Fig. 3 and Table 1, the preliminary system break-up for weight distribution, and vehicle space utilization consists of eight (8) separate units. Liaison with responsible contracting personnel during the study phase will either confirm this division or suggest one more compatible with the aircraft installation.

In the following discussion the general operating principles of a pulsed radar will be assumed, and discussion reserved for those units and principles of operation which may not be normally associated with conventional radar techniques. Let it then suffice as a starting point to state that the presentation consists of a slightly modified "C" type display. The departure from the conventional display is that instead of displaying only the targets within some small increment of range, ΔR, we wish to display all targets from some nominal initial range, R; to the maximum required range, Rm. Further, we wish to identify each target with approximate range information, so that this information, coupled with the angular position relative to the flight line,

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may indicate to the operator the need of flight line correction and also the required timing of the correction to allow a suitable safety margin commensurate with both the proximity of the obstacle and the hazards of higher altitude.

It is not necessarily obvious at first glance, but a little thought reveals that the integration effect of noise on the CRT rules out the utilization of pure video for display purposes on a C-type presentation of this depth. Rather, the system must automatically detect targets with a good degree of certainty, and then generate a high intensity pulse - the CRT being cut-off at all other times. Various methods of target detection and multi-color range display are covered in detail under Par. Vc, Indicator, so no expansion of these two functions will be made at this point. However, there is a system limitation generally associated with indicators, but conspicuously absent in the detailed discussion of that unit. This is the system resolution. In various short pulse mapping systems of moderate and long range, the minimum spot size of the CRT limits the definition obtainable on the display. However, in a C-type presentation, the scaled magnitude of the beam dimensions obtainable with practical size antennas is very large in relation to even nominal spot sizes, consequently the limit to resolution is completely dependent on antenna size. Following this line of reasoning, we may roughly compute the number of independent picture elements from the -3db beam dimensions in degrees and the scanned volume in degrees:

$$\text{No. of vertical elements} = \frac{\text{Vert. Scan Angle}}{\text{Vert. Ant. beam width}}$$

$$\text{No. of horizontal elements} = \frac{\text{Hor. Scan Angle}}{\text{Hor. Ant. beam width}}$$

Total picture elements = (No. vert. elements) x (No. Hor. elements)

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It will be recalled from Fig. 3 that this system utilizes separate antennas for the transmitting and receiving functions. These are crossed linear arrays discussed in detail under Section (Ve), Antennas. The transmitting antenna has a beam shape which is wide in the horizontal plane and narrow in the vertical, while the receiving antenna has the converse pattern - narrow horizontally and wide vertically. The combined effect produces a high resolution area in the region of space where these two patterns intersect, and the displayed raster is then generated by rapidly scanning the horizontal or receiving antenna from side to side and slowly scanning the vertical or transmitting antenna up and down.

With the brief discussion of the indicator and antenna system fresh in mind, the complex system variable which must be solved during the study phase will be introduced. As a basis we may start with the three prime requirements in a very generalized form: First - that the system have sufficient gain to detect possible hazzards at a range commensurate with pilot reaction time and aircraft maneuverability; second - that the angular definition be sufficiently fine so that the clearance of the projected flight path and an obstacle may be predicted with a "reasonable" degree of accuracy; and third - that the system be compatible in bulk, weight, and added protrusion from the aircraft so as not to materially degrade the operational characteristics of the aircraft.

Pertinent variables which affect system gain are:

(1) Transmitter peak power

(2) Receiver bandwidth

(a) pulse width

(3) Antenna aperture size

(4) Pulses per beamwidth (scanning function)

(5) R.F. Efficiency (Noise Figure, Losses, etc.)

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Those affecting definition and reliability:

(1) Antenna aperture size

(a) Scanning element size

(b) Frame rate

(2) Pulse Repetition Frequency

(3) Transmitter peak power

(4) R.F. Efficiency

Those affecting aircraft installation or performance:

(1) Antenna aperture size

(2) Transmitter peak power

The critical aspect of this listing is that a number of dual and in some cases, triple inclusions exist. In general, variation of a factor in order to improve one of the three basic requirements results in a compromise of one of the other requirements.

TABLE 1

LIST OF UNITS

UNIT	SIZE
Power Supply	12 x 12 x 15
Indicator	8 x 8 x 15
Receiver	12 x 6 x 6
Modulator and H.V. P.S.	12 x 12 x 12
Transmitter	12 x 8 x 8
Elevation Antenna	3½ Foot linear array
Azimuth Ant.	1½ Foot Scanner
Flight path data unit	6 x 6 x 12

Estimated overall system weight - 350 pounds.

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IV. Typical Configuration

The proposed system parameters are listed in Table 2. These are solved below for the various system operating criteria and, in the case of the antennas, the physical sizes required.

In Table 3 the radar range equation has been solved for three target sizes - 1 meter^2, 5 meter^2 and 50 meter^2. These solutions give free-space ranges of 4.6, 6.9, and 11 nautical miles respectively. Introducing 0.3 db per mile atmospheric attenuation these ranges are corrected to 3.7, 5.6, and 7 nautical miles respectively, which should satisfactorily fulfill the range requirements of the task. These ranges, though quite sufficient for the task, are short in comparison to those normally available in conventional or side-look radar. This is primarily due to the crossed beam antenna where we suffer a 20.8 db two-way loss over the sum of the theoretical one-way gains of each. Another method of stating it more clearly is that the four foot radiator used for the transmitting and receiving functions would contribute 78.8 db to the system gain. Crossing this antenna with the 1½ foot horizontal antenna contributes only 63.2 db for a system loss of 15.6 db over conventional scanning.

The antenna beam widths quoted in Table 2 may be obtained with a four (4) foot vertical linear array and an 18 inch horizontal array. The apertures required for the wide dimensions of the respective beams would be roughly 1½ inches for the vertical and 9 inches for the horizontal antenna. Thus the frontal area required for totally external radomes would be roughly 4½ feet by six inches (required for mounting rather than aperture) and 1½ foot by 1 foot for a total of 3.75 square feet added on the vehicle front profile. Various schemes for completely flush-mounted, and partially flush-mounted

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Systems are given under the section devoted to installation.

The transverse packet dimensions of $0.5^{\circ} \times 1.5^{\circ}$ and transverse scan dimensions of $10^{\circ} \times 30^{\circ}$ provide 20 horizontal and 20 vertical elements, or 400 resolvable elements per frame. The pulse repetition frequency of 1600 pps, times 2 seconds/frame divided by the number of resolvable elements gives eight hits per beamwidth. For any given element area, 4 pulses are integrated on the left to right traverse of the beam, and four more on the return. With this arrangement we are assured that there will be no gaps in the vertical raster, and by using storage tubes for the display the two groups of four pulses are all integrated to give the quoted eight pulses/target traverse.

The 0.5° vertical beamwidth subtends a chord 8.7 ft./1000 ft. of range or 261 ft., at 5 miles range. This is ample to define a 500 foot object at this range within the accuracy of a beamwidth. Corrections to flight path would probably not be made at this range, but more than likely at two miles or a little greater, at which time the peak of the obstruction would be displayed within an accuracy on the order of 100 feet. At any rate a planned 500 foot clearance of the object would contain a great safety margin with this system.

The final pertinent factor to be discussed is the rate of flow of information. Within the system there is, of course, essentially a continuous flow, but to the operator it would be the frame rate or one complete view every two seconds. At 300 knots the viewed interval of five miles would be covered in one minute flying time. The two second frame rate would provide 30 complete looks during this time, or in other words, a new picture would be presented for every thousand feet of forward motion.

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TABLE 2

SYSTEM PARAMETERS

Vert. Antenna beam width	$0.5^\circ \times 30^\circ$
Hor. Antenna beam width	$1.5^\circ \times 3^\circ$
Transmitted frequency	35 KMC
Pulse width	0.25 usec
Peak Power	70 KW
Repetition Frequency	1600 pps
Receiver Bandwidth	4.8 MC
Horizontal Scan Velocity	10 cps
Vertical Scan Velocity	0.25 cps
Frame rate	1 frame/2 sec.
Scan Volume Dimensions	
Horizontal	30°
Vertical	10°

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TABLE 3

Typical System - Range Solution

Factor	Size/Quantity	+db	-db
Vert. Ant.	4' (.5° x 30°)	39.4	13
Hor. Ant.	9" x 18" (1.5° x 3°)	44.6	7.8
Pk. Pwr.	70 KW (0.25 usec)	47.4	
λ Fact.	35 KMC		63.5
T_A (Target Area)	1; 5, & 50 M^2	6 (50 M^2)	11 ($1M^2$) 4($5M^2$)
N.F.	10 db		10
KTB (Rec. Gain)	4.8 MC b.w.	137.2	
tB	1.2	.5	
Hits per beam width	8		6.2
System Gain excluding T_A Function		+269.1	-100.5
		-100.5	
		168.6	

T_A	$1M^2$	$5M^2$	$50M^2$
System Gain excluding T_A	168.6	168.6	168.6
T_A	-11	-4	+6
Total System Gain	+157.6	+164.6	+174.6
Range (free space)	4.6 naut. mi.	6.9 naut. mi.	11 naut. mi.
Range assuming .3db/mi.	3.7	5.6	7

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V. Detailed Discussion of Equipment

A. General

Table 1 lists the major units which will be designed and constructed during phase three of the program. The present XMA-1 equipment will form a basis for the design with the individual parameters being tailored to the requirements of the mission considered here. The design of a large portion of the equipment can be undertaken at once since it will not be affected by the study program. For this portion of the equipment the study phase will be devoted to selection of specific circuitry and component values.

A brief resume of some of the more important parameters of the individual units of the equipment will be given below.

B. R. F. Units

The transmitter and receiver units follow conventional radar practice. The magnetron tube proposed is the MA-207 ruggedized tube developed by Microwave Associates. This tube has been evaluated in our laboratory and found to give excellent performance. It is ruggedized to withstand aircraft shock and vibration.

The klystron will be a Varian Associates VA-97. This tube represents an order of magnitude improvement over any other K_a band tube. It is equal to most X band tubes in ease of application, stability and life.

The crystals will be Sylvania D936 units, these crystals have a maximum conversion loss of 6.5 db. This, coupled with the fact that the proposed system does not require the use of a duplexer, assures an overall R.F. noise figure of 10 db or better.

The receiver will use conventional subminiature tubes for the low noise pre-amplifier and R.F. transistors for the post-amplifier if delivery

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of the transistors permit, otherwise, subminiature tubes will be used in the post-amplifier as well.

The video output from the post-amplifier will be processed by a range quantizer unit which will divide the received video into discrete range segments for further processing by the integrating detector in the indicator. All of this circuitry will be transistorized.

The magnetron and pre-amplifier will be located as close as possible to the transmitting and receiving antennas to minimize waveguide losses.

C. Indicator

The indicator will display two types of information: (1) a transverse profile and (2) a flight line range-elevation profile for the ground track position of the azimuth scan. (See Fig. 2)

The transverse profile will consist of a modified "C" scope display. In this display azimuth is plotted versus elevation on the X and Y axes respectively. A simulated Z axis which displays range will be formed by the use of two or more contrasting colors or light intensities. The azimuth and elevation deflection of this profile will be proportional to the beam angles in space. Range information is quantitized into segments and is displayed in the appropriate color or shade. Video received during a particular range segment appears in the color (for example red) corresponding to that segment only. Thus, the first color shows all radar targets (obstructions in the first range segment, the second color the second segment, etc.

A method of implementing this transverse profile would be to present the video of the various range segments on time shared or separate traces of one or more storage tubes. The separate displays would then be filtered for color contrast and combined optically. The flight line plot could be presented

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in similar fashion. Figure 4 shows how the two profiles, flight line and transverse, may appear on one dual gun storage device. These images could then be combined with indices to form a display similar to the one shown in Fig. 2.

Since the transverse profile is essentially the combination of C-scope displays, steps must be taken to improve the notoriously poor signal to noise ratio found in such a display. The problem arises from a situation equivalent to collapsing the range trace of a PPI into a single spot. The usual method of improving the situation is to limit the range of video displayed on the C-scope. This possibility is ruled out; since in the proposed system, the targets of interest will be contained in about a 7 mile range.

Experimental work with this problem has led to the use of an integrating detector on previous similar systems. Fig. 3 shows the block diagram of a device that improves the signal to noise ratio appreciably. The CRT is held cut off until the detector, after an alarm and one or more integrations, "decides" a signal is present. Other techniques are available similar in principle to the one shown in Fig. 4.

A block diagram of the indicating system is shown in Fig. 5.

The vertical flight line profile is generated by a coincidence circuit which senses the period in which the antenna system is viewing the flight ground track line. At this instant video information is fed to the range-elevation indicator. This type display has proved confusing to pilots, but desirable for navigators use. The proposed system gives both types of display since this is possible with a minimum of added complexity.

A majority of the detector circuitry and a considerable amount of the switching and synchronizing circuitry will be transistorized to reduce weight, bulk and heat.

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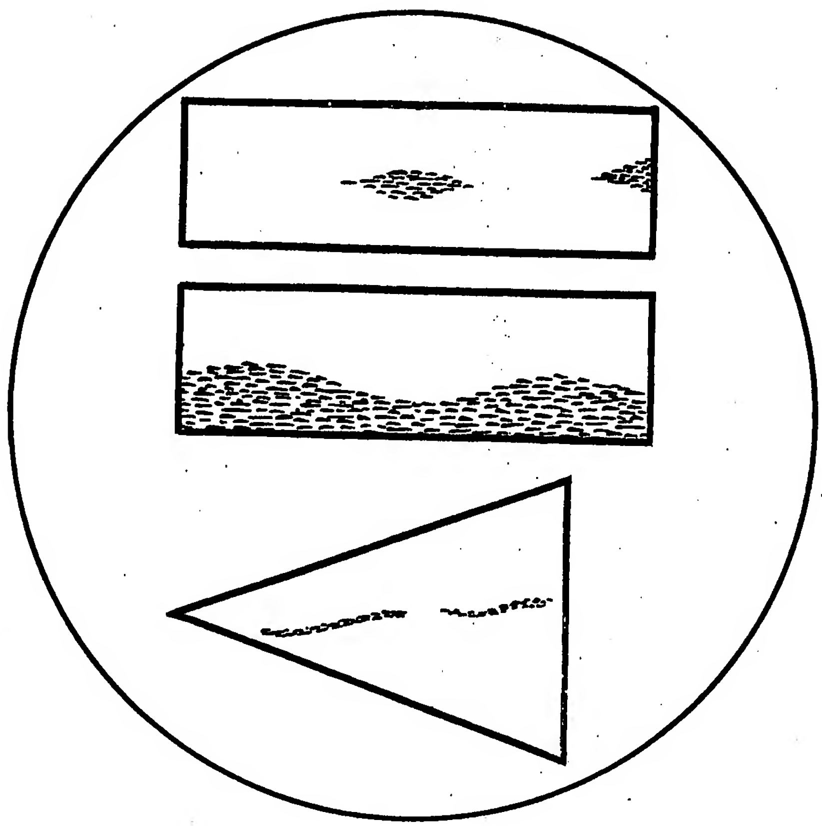

DISPLAY ON STORAGE TUBE

FIG. 4

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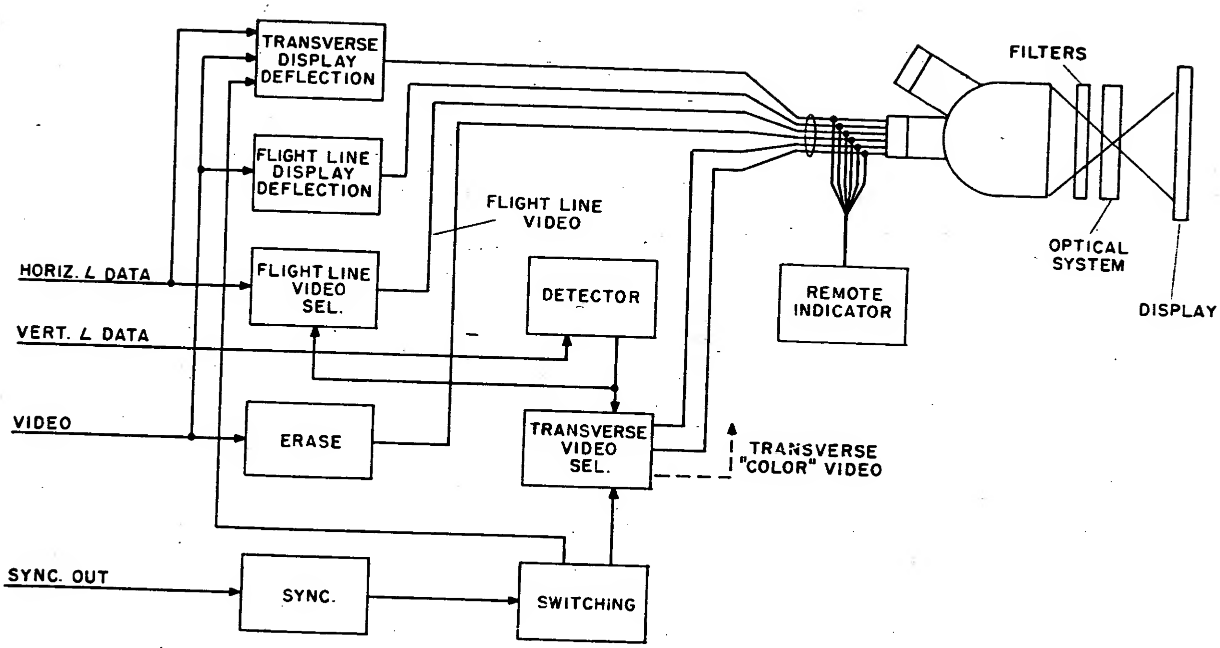

INDICATOR BLOCK DIAGRAM

FIG. 5

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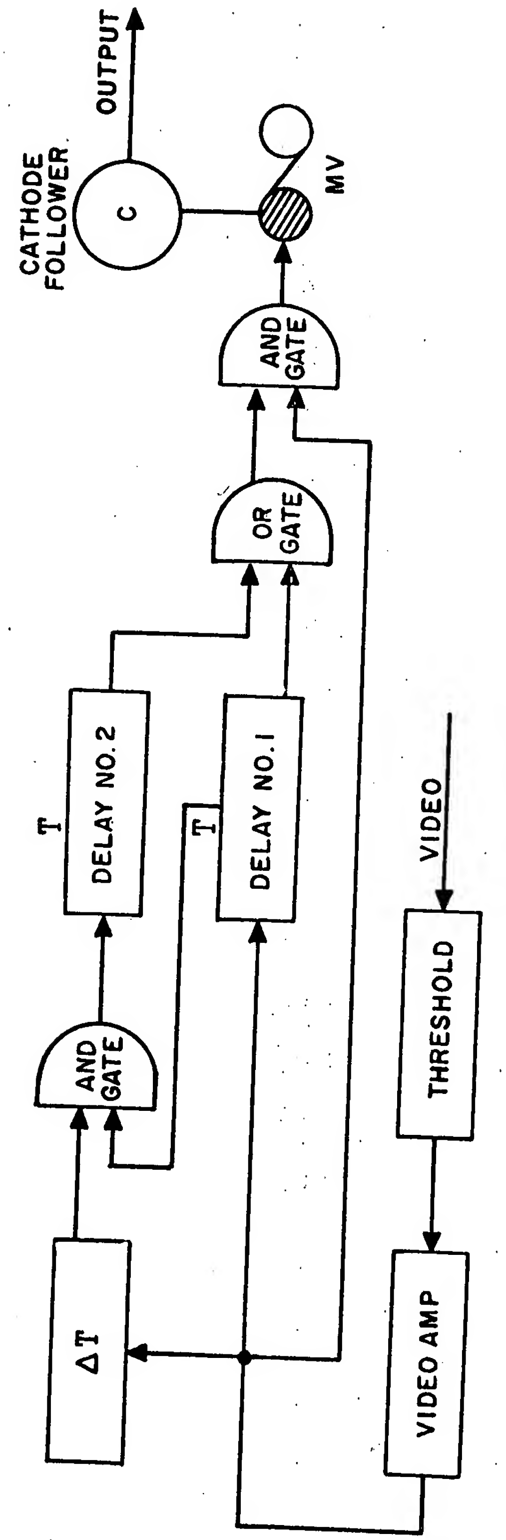

DETECTOR: FIGURE 5A

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The development and construction of the indicator for the proposed Terrain Clearance System will be aided by the efforts and experience of a group of engineers at this facility, whose main concern is with investigations and developments in the general field of radar indicators. In addition, other groups in the organization have had considerable experience solving the specific problems encountered in designing Terrain Clearance System indicators. Displays using both the shadow-mask color tube and the Lawrence color tube have been designed and built, and both exhibit faults that make their use in an operational Terrain Clearance System of doubtful value. Both exhibit the fact that color phosphors suitable for radar work are not yet perfected. The color purity is very poor, and the light decay characteristics of the different colors vary widely, in comparison to each other. This does not appear to be a problem that the tube manufacturers will be able to solve in a short time.

The shadow-mask tube has the additional major fault that the magnetic convergence circuits are upset by any external magnetic field. Movement through the earth's magnetic field is sufficient to do this. For that reason alone, it appears to be unsuitable for use in the airborne environment.

The Lawrence tube color-switching grid structure is rather delicate and is marginal for use under vibration conditions met in the airborne environment. In addition, its display intensity is so low that viewing through a hood is mandatory, even in subdued ambient light, and this makes it unsuitable for use in an airplane.

Fortunately, the situation with respect to storage tubes is literally much brighter. Two types are available which can produce display intensities approaching a hundred or more times the brightness of a home television display.

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Farnsworth has its Iatron single-gun tube in production in 3 inch and 5 inch screen sizes. It can be had with either magnetic or electrostatic deflection and can produce light intensities up to 8,000 ft.-lamberts.

RCA has a 5 inch single-gun storage tube in production with electrostatic deflection, and a display intensity up to 2,000 ft.-lamberts. Engineering models of a two-gun storage tube are also available from RCA, with a 3 to 4 month delivery delay. A 10 inch tube will be available much later.

Hughes, Westinghouse and Dumont also have storage tube development programs. The Westinghouse and Dumont developments are similar to the Iatron, but not yet near the production stage. Hughes is unique in having a color storage tube under development, the first models of which will be ready in 6 to 7 months. Unfortunately, this tube is of the shadow-mask type and will have the same inherent faults as was previously discussed for that type. The indicator group has models of the Farnsworth and RCA storage tubes on hand, and has already accumulated considerable experience.

The indicator that will be built for the proposed system will be considerably influenced by this experience. The RCA tube is considered to be superior in some respects, namely, placement of the high voltage connections for safety, and general ruggedness and symmetry of construction. If the 2-gun tube is used (depending on its availability), the displays could be accommodated with one tube; one gun would be devoted to the flight-path range-elevation display and one gun time-shared for the transverse profiles. Each of these displays will be filtered through pure optical color filters and combined on one viewing screen through a lens and prism system. The display intensity is easily great enough to produce a brilliant combined display even after the light losses imposed by the optical and color filter system. Single-gun tubes

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would require a bank of two tubes for the same display.

The resolution capability of both tubes is 50 lines per inch, which is sufficient to display all the radar resolution of the system.

The maximum display image size with two displays on a 5 inch 2-gun tube would be approximately 1.2 inches by 2.8 inches each. With one display per tube it would be 2.5 x 2.8 inches.

The storage time these tubes are capable of is from 2 to 10 seconds which is amply sufficient for the proposed two second frame time.

Another advantage of using storage tubes is that the decay characteristic of the image is approximately linear with time and the slope of the characteristic is controllable by a straightforward video pulse erasing technique. To the eye, the picture appears to be of almost uniform brightness, which decays evenly, rather than a bright portion immediately following the sweep, but decaying rapidly away from the sweep, as in the normal exponential decay of non-storage tubes.

D. Antennas, General

A study of antenna design work being done, together with experience already gained on the XMA-1 Terrain Avoidance Project would serve to set the general characteristics of the antennas. Some antenna projects in progress may be incomplete as regards the specific goals of the projects, but portions of them may be applicable to Terrain Avoidance requirements. For instance, reciprocal directivity is a serious problem in some ferrite antenna development projects. In the system proposed here, that problem does not exist because separate receiving and transmitting antennas are used.

The antenna problem is in general one of finding the best way of providing the required aperture. Once the angular accuracy requirements and the

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operating frequency of the radar system are decided upon, the aperture size is fixed.

The general antenna design proposed for the system will probably be some form of linear array for both receiving and transmitting, arranged in a crossed configuration, but some other types have attractive characteristics and these will be considered. The linear array is probably the most economical of aircraft volume and offers the possibility of being so located that the nose area of the airplane is left clear for other purposes. In addition, the effective beamwidth achieved is a pencil beam equivalent in cross-section to the narrowest dimensions of the two crossed fan beams. For instance, a transmitting fan beam 10° wide in elevation and 1.5° wide in azimuth crossed with a receiving fan beam 30° wide in azimuth and $1/2^{\circ}$ wide in elevation results in an effective elliptical pencil beam measuring $1\ 1/2^{\circ} \times 1/2^{\circ}$. The disadvantage to this is that some power is wasted outside the intersection of the two fan beams.

The study of techniques and methods of constructing antennas and scanning them will consume the time allotted to the antenna problem. Some of the types that will be considered are described below.

E. Types of Antennas

a. Arrays of discrete radiators related in phase and amplitude to produce a desired pattern. At the wavelengths which would be considered for the proposed system, dipoles are not practical, so some kind of slotted or "leaky" waveguide would be considered. These can be arrays of transverse slots cut across the narrow face of the waveguide, slots in the broad face of the waveguide, parallel to each other and to the direction of propagation, or simply rows of round holes of varying size.

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b. The other major category of slotted waveguide arrays is the traveling wave slot antenna. It radiates from a long slot down the length of the waveguide. This type of array appears to be of considerable practical importance because it is much easier to construct than the more common array of discrete half-wave slots. Phase and amplitude control are exercised by varying the waveguide depth and slot width.

Another very interesting possibility in connection with traveling wave slot antenna design is that a graphical method for designing such antennas to fit an arbitrary curved surface has been developed by the Ohio State University Research Foundation. It is possible that using this technique, a linear array which follows the contour of some part of the aircraft fuselage could be designed. The effective aperture of such an array would, of course, be the projected aperture in the direction of radiation. This might mean that an array six feet long would be required in order to get an effective aperture of say, three feet. This is a small price to pay if it results in minimum aerodynamic distortion of the aircraft.

c. Reflectors illuminated by one or more horn feeds, or a line source. This technique has the advantage of years of design experience behind it, and design data exists for numerous variations of the basic configuration.

F. <u>Scanning Methods For Antenna</u>

In general, a Terrain Avoidance System should scan a pyramidal volume of space ahead of the aircraft. Figure 6 illustrates the general scan coverage required for either transverse or vertical profiling. The scan can be in raster form with the fast scan drawing either vertical or transverse lines. Several scanning methods will be considered for the antenna system.

1. Mechanical movement of the entire antenna structure, such as is done with the vertical antenna on the XMA-1 Terrain Avoidance System.

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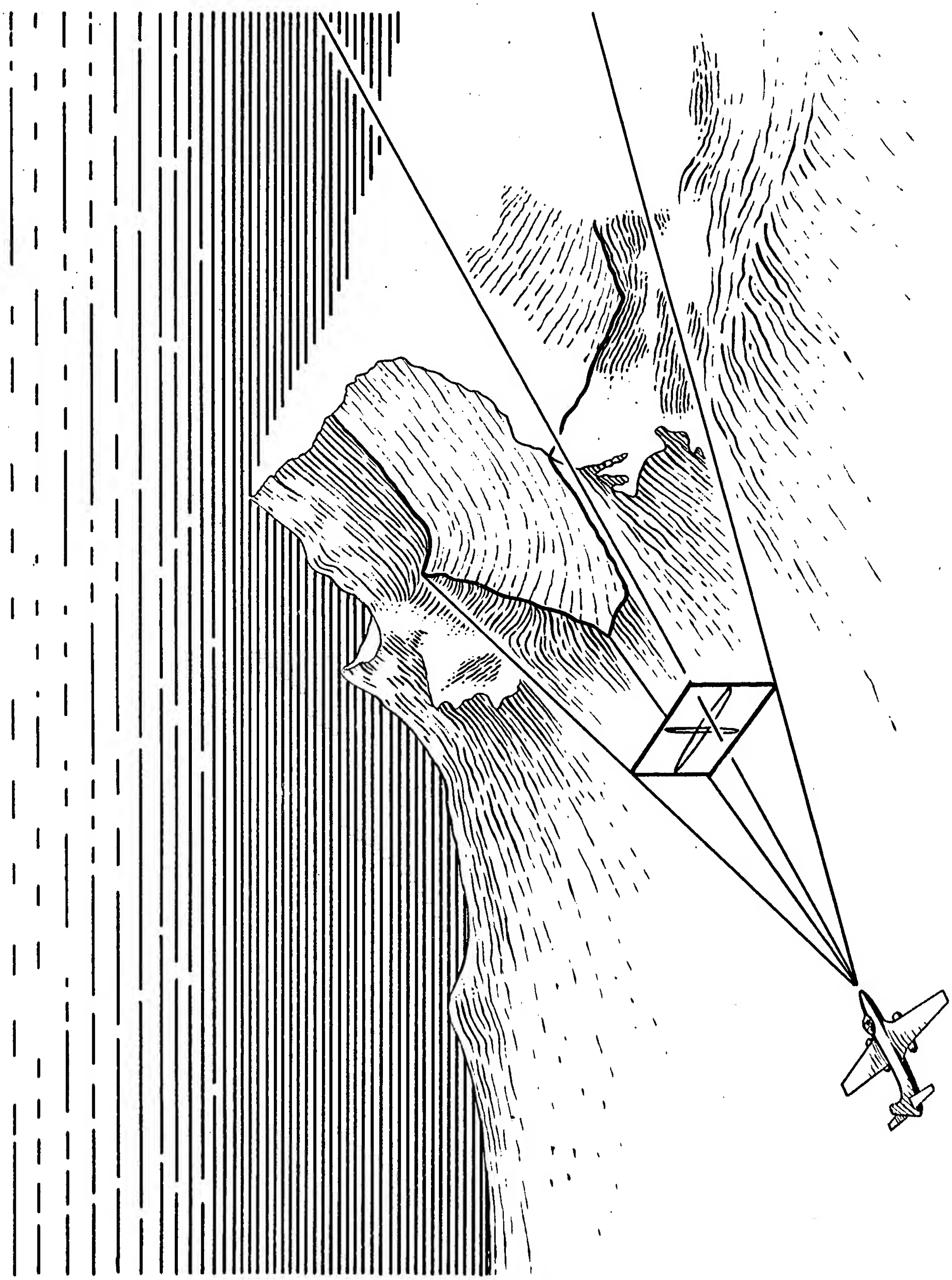

FIG. 6 - ANTENNA COVERAGE DIAGRAM

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2. Mechanical movement of the feed with respect to a fixed reflector or lens.

3. Mechanically induced phase shift such as employed on the XMA-1 horizontal antenna where an array of slots in waveguide with a moving back wall is employed.

4. Electrically induced phase shift of a slotted array produced by magnetically modulated ferrites in the waveguide.

5. Frequency shift scanning.

Mechanical scanning methods such as described in 1 and 2 may be entirely impractical due to aerodynamic and space limitations when applied to ten foot apertures, but they may be eminently practical when applied to one foot aperture antennas, and both of these aperture sizes have been considered for Terrain Avoidance Systems. Therefore, the method of scanning to be used will depend to a considerable extent on the aperture size decided upon as best for the proposed system.

Figure 7 shows an example of feed and reflector combination giving the required coverage for either vertical or transverse profiling with a single pencil beam.

An elliptical parabolic reflector is illuminated by a trapezoidal horn and the whole array rotated about the vertical axis to produce $\pm 15^{\circ}$ azimuth scanning at a rate of about 1/4 cycle per second. A rotating waveguide feed scanning the apex of the trapezoidal horn produces the rapid vertical scan. It has the advantages of using straight forward techniques and of developing maximum gain because all the energy is concentrated in a single pencil beam. On the other hand, it results in a complex mechanical assembly that takes up considerable space and requires considerable driving power.

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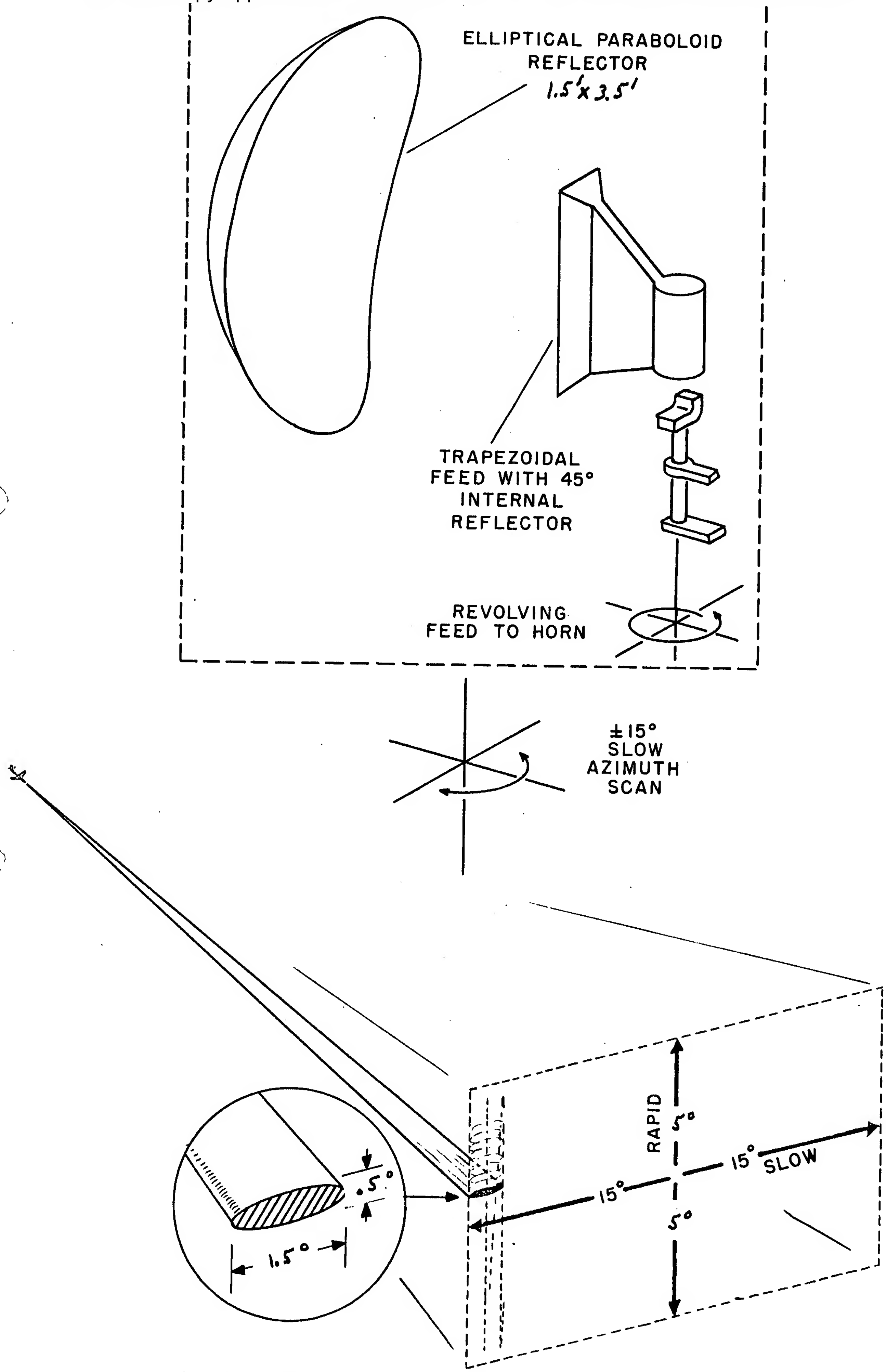

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The scanning method of No. 3 can result in a very complex structure involving much precision machining, as it did in the example cited. If, however, the mode of propagation in the waveguide is changed from the conventional TE_{01} to TM_{11} and the waveguide cross-section made more nearly square; and the radiator changed from an array of discrete slots to a traveling wave slot, the structure becomes much easier to build. The moving back wall now moves with the electric field rather than across it, and this eliminates the requirement for a precision machined choke groove in each edge of the moving wall. It also reduces the requirement for a very precise fit between the moving wall and the stationary walls. Another method of scanning by mechanically induced phase shift is possible in this array too. Instead of a moving back wall, a "moving ridge" can be used. This is a thin plate moved in and out of a slot down the side of the waveguide. The mechanical complexity is about the same.

Figure No. 8 is a simplified representation of mechanically induced phase shift scan applied to both antennas. The scan shown is of the transverse profiling type.

The scanning method of No. 4, involving the use of ferrites has considerable appeal because there are no mechanical moving parts. There are many problems involving the need for waveguide of a constant cross-section, ferrite material of good uniformity and the production of a uniform magnetic field. The method requires considerable work and investigation to determine its feasibility. Recent advances in the field of microwave ferrites lend a degree of optimism to this approach and it will be thoroughly investigated during the early portion of the program.

Figure No. 9 shows ferrite scanning technique applied to crossed linear arrays with a transverse profiling scan.

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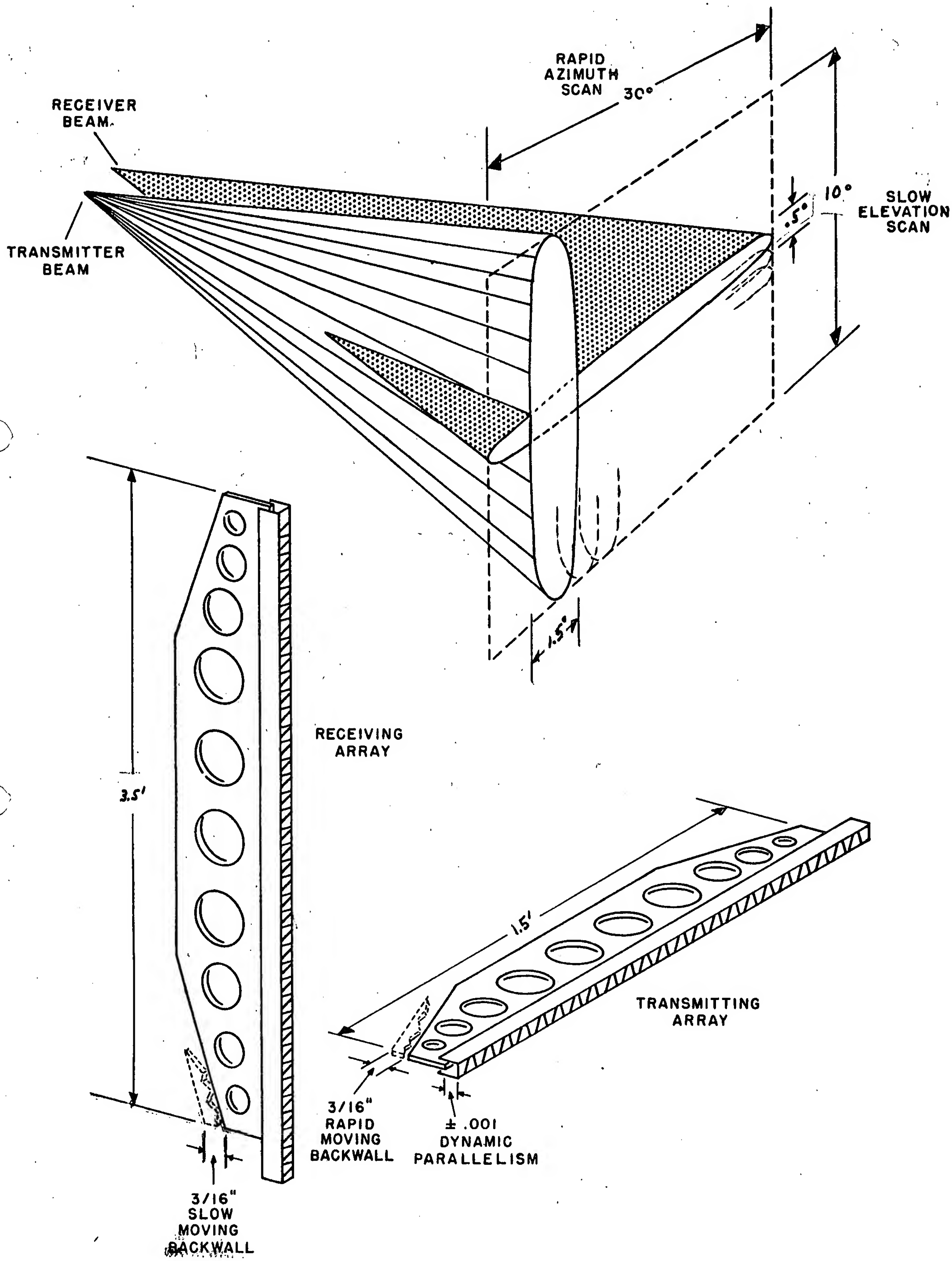

FIG. 8 – MECHANICAL PHASE-SHIFT SCANNED ANTENNA

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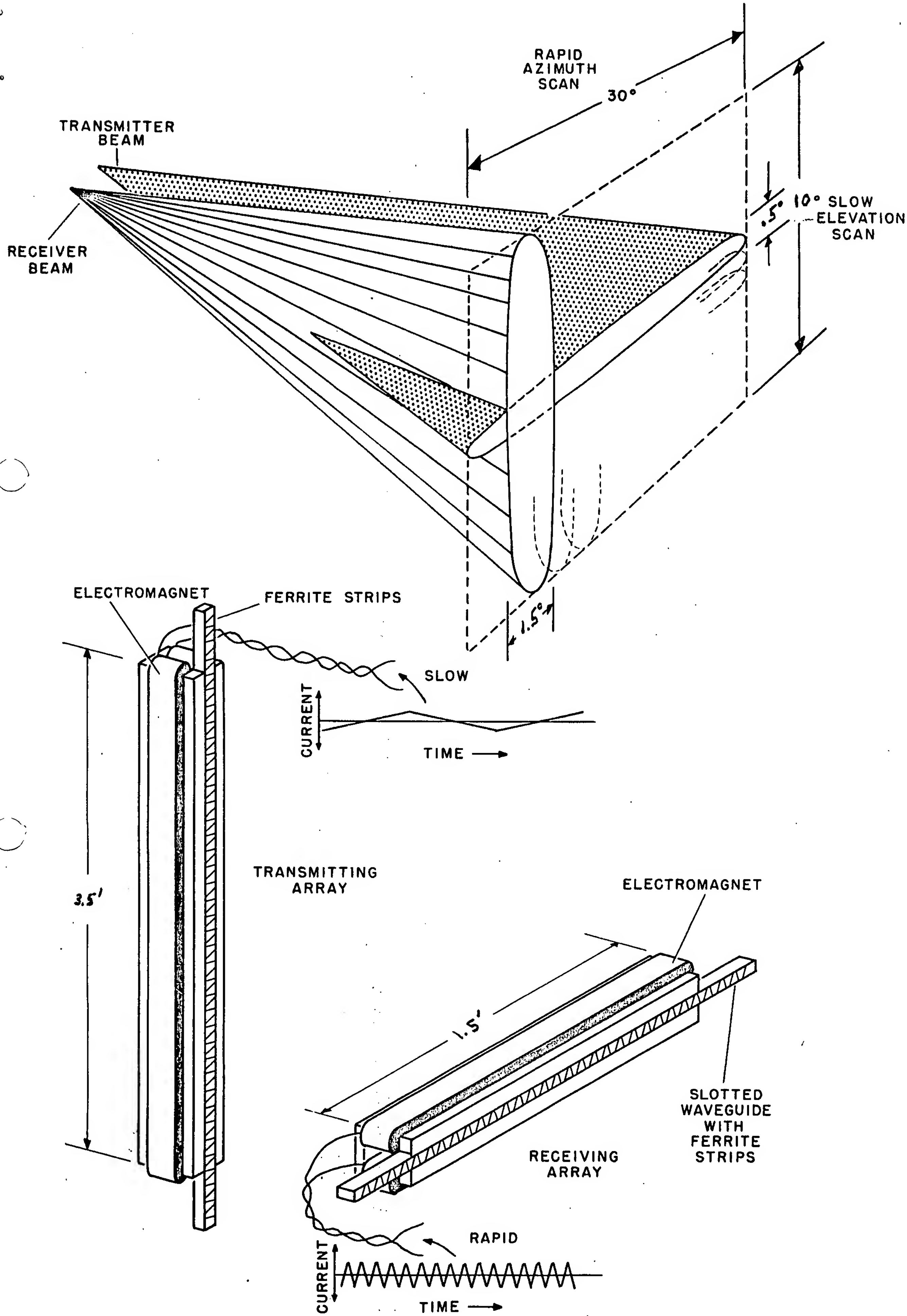

FIG. 9 - FERRITE PHASE-SHIFT SCANNED ANTENNA

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Number 5, frequency shift scanning does not appear to hold much promise, partly due to lack of reliable variable frequency sources, but mostly due to the fact that the frequency shift would affect both antennas at once, and the resultant shift of the scan would be along a diagonal line, rather than cover a raster as at present contemplated.

G. Practical Antenna Configuration

A description of a practical antenna system for the proposed radar is given below. The parameters selected here are for illustration only. The exact beamwidths and scan rates will be determined during the study phase.

The transmitting antenna would radiate a horizontal fan beam 1° wide in elevation and 20° wide in azimuth. This beam would scan a vertical sector of 10° at a rate of 1 cycle per 2 seconds; that is, one scan up 10° in one second and one scan down 10° in one second. This antenna would require a vertical aperture of about 24 inches and a horizontal aperture of about 1-1/8 inches.

The receiving antenna would have a fan beam 2° wide in aximuth and 5° wide in elevation, and would scan a horizontal sector of 20° at the rate of 25 cycles per second. It would require a horizontal aperture of about 12 inches and a vertical aperture of about $4\frac{1}{2}$ inches. The receiving antenna would also scan vertically in unison with the slow scan transmitting antenna so that the two-way gain of the antenna system is maximized. The intersection of these two beams form an elliptical pencil beam $1^{\circ} \times 2^{\circ}$ which performs a raster scan containing 50 horizontal lines within a sector $10^{\circ} \times 20^{\circ}$ and having a frame time of one second. The 2-way gain of this system is estimated to be about 50 db.

The polarization of crossed arrays is normally crossed and a power

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loss on target returns results from this. The chief reason this power loss is not total is because a large component of the return signal is randomly polarized with respect to the transmitted signal. (Actual tests on the XMA-1 system have shown this loss to be quite small). This polarization loss can possibly be minimized however, by using another technique developed by the Ohio State University Research Foundation. Placing parallel plates which flare into a space-matching horn in front of the radiating surface of a linear array produces a direction of polarization of the energy chiefly dependent upon the length of the parallel plate section of the horn. It becomes fairly straightforward then to design crossed arrays which are parallel polarized, and this would minimize cross-polarization loss. The desirability of adding this refinement to the system will be evaluated.

The system could be contained in two airfoil stubs mounted atop the pilots' cabin in a T or inverted T configuration. Allowing for supporting structure and fairing, the vertical airfoil might be 36" high by 4" wide and the horizontal airfoil 18" long by 7" thick at its thickest point.

This antenna system will give a vertical resolution of 105 ft., per nautical mile of range and an azimuth resolution of 210 ft., per nautical mile of range.

H. Flight Path Data

The radar system gives a simulated three dimensional picture of the terrain ahead of the aircraft. To be of maximum usefulness to the navigator or pilot, additional information is required which will show the aircraft flight path in relation to the terrain. A typical flight configuration is shown in Figure 10. Only in rare cases does an aircraft heading alone determine the ground track of the aircraft. Wind introduces a drift angle while aircraft

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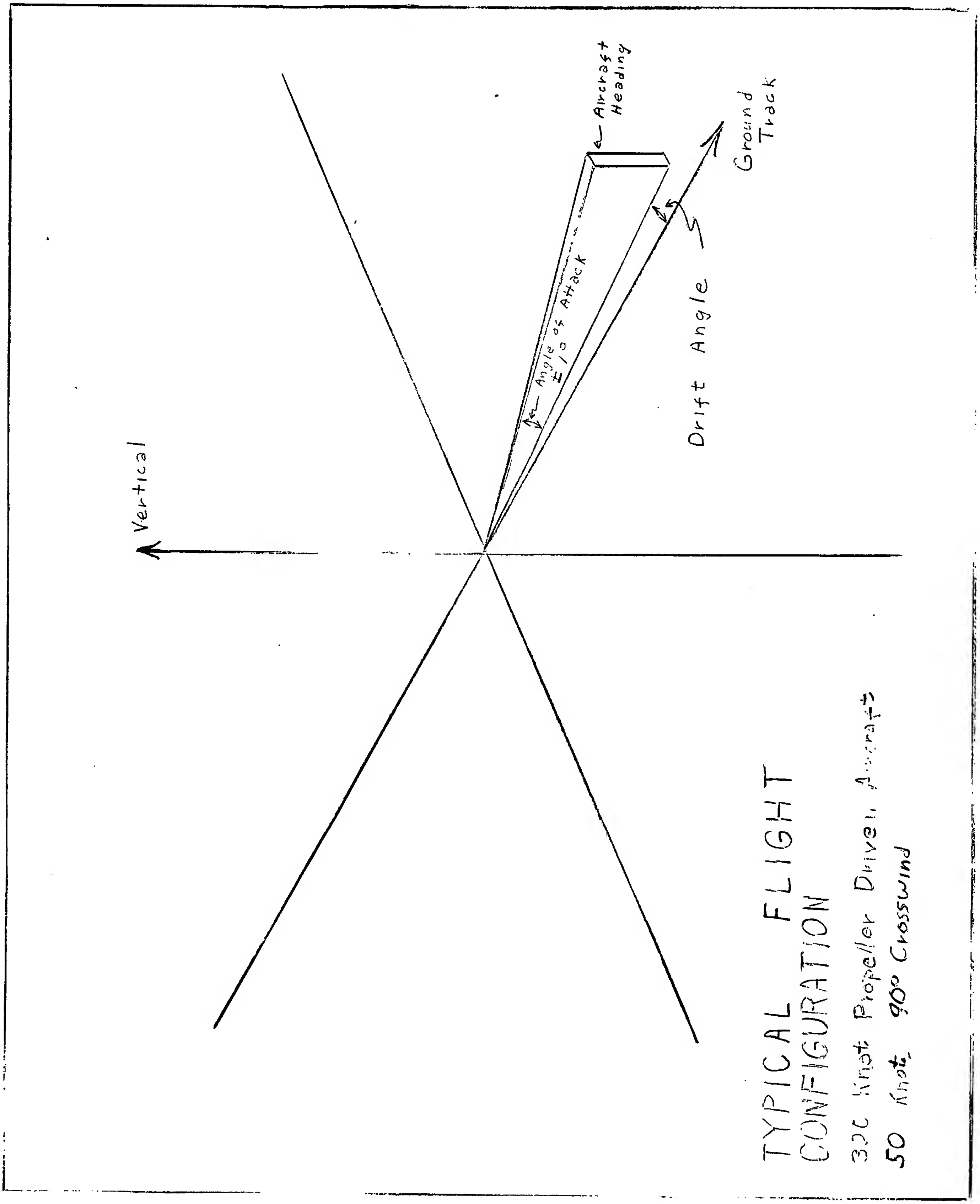

FIG. 10

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trim, load distribution, etc., introduce a pitch angle.

Both angles can be compensated for either by data stabilization or antenna stabilization. Data stabilization requires that the antenna coverage be increased sufficiently to insure radar coverage of the ground track even in cases of extreme drift angle. Antenna stabilization requires the use of larger radomes and added complexity but does result in increased system gain.

Measuring the drift and pitch angles requires considerable equipment fortunately, however, this information is normally available from other equipment and its use for terrain avoidance does not represent an increase in overall aircraft complexity.

The exact tie-in with other equipment will be determined during the study phase. One possible source of the information is from a doppler radar such as the APN-81 or RADAN equipments.

A 250 to 300 mile per hour class of aircraft at a level flight speed of 270 knots would typically have an angle of attack of -1° for fuselage reference line and 0° for armament datum line. If the aircraft were subjected to a 60 knot 90° crosswind, the maximum crab angle would be 12°. These angles are small enough that data stabilization is indicated. The antenna coverage pattern will be sufficient to encompass the flight path line at all times without resort to stabilization of the antenna arrays.

The flight path data may be added to the display either mechanically or electronically. The final choice will be determined after a careful study of the indicator problem.

It will be necessary to design a flight path data unit. This unit will be essentially a servo amplifier to accept drift and angle of attack information and will supply the necessary control signals to position the aircraft flight path indicator.

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VI. Installation Considerations

Figure 11 through 14 shows four possible antenna schemes. Figure 11 is completely flush mounted in a manner somewhat detrimental to the de-icing capability of the aircraft, but is ideal in the respect that no protrusions from the airframe are required. Figure 12 has the two antennas mounted in separate radomes, the vertical on top of the pilot's compartment and the horizontal under one wing. These two methods impose a system difficulty in that it would require coupling of a sample of RF energy from the vertical antenna to the horizontal antenna in order to perform the AFC function. This would have to be done by running waveguide between the two antennas, or by transmitting a sample through a small tap-off horn to a pick-up horn in the proximity of the receiving antenna.

The configurations of Figure 13 and 14 are believed to be the most functional in respect to both aircraft modification required and to system simplicity. In Fig. 13 the receiving antenna is contained in a base on top of the pilot's compartment, and the vertical antenna in a streamlined spar on top of the base. An alternate of this method would be to place the receiving antenna at the top of the spar in a two foot wide "wing section". Figure 14 illustrates the proposed system in which one wing tank would be utilized to completely contain the horizontal antenna.

Both the Figure 13 and 14 systems offer the same general advantages. In order to get a safety factor in the system gain of the proposed system, the horizontal antenna pattern has been restricted to three degrees in the vertical plane. This means that in addition to its horizontal motion, the receiving antenna must also follow the transmitting antenna in its vertical motion. With the relatively slow scan rates planned, this involves a minor mechanical

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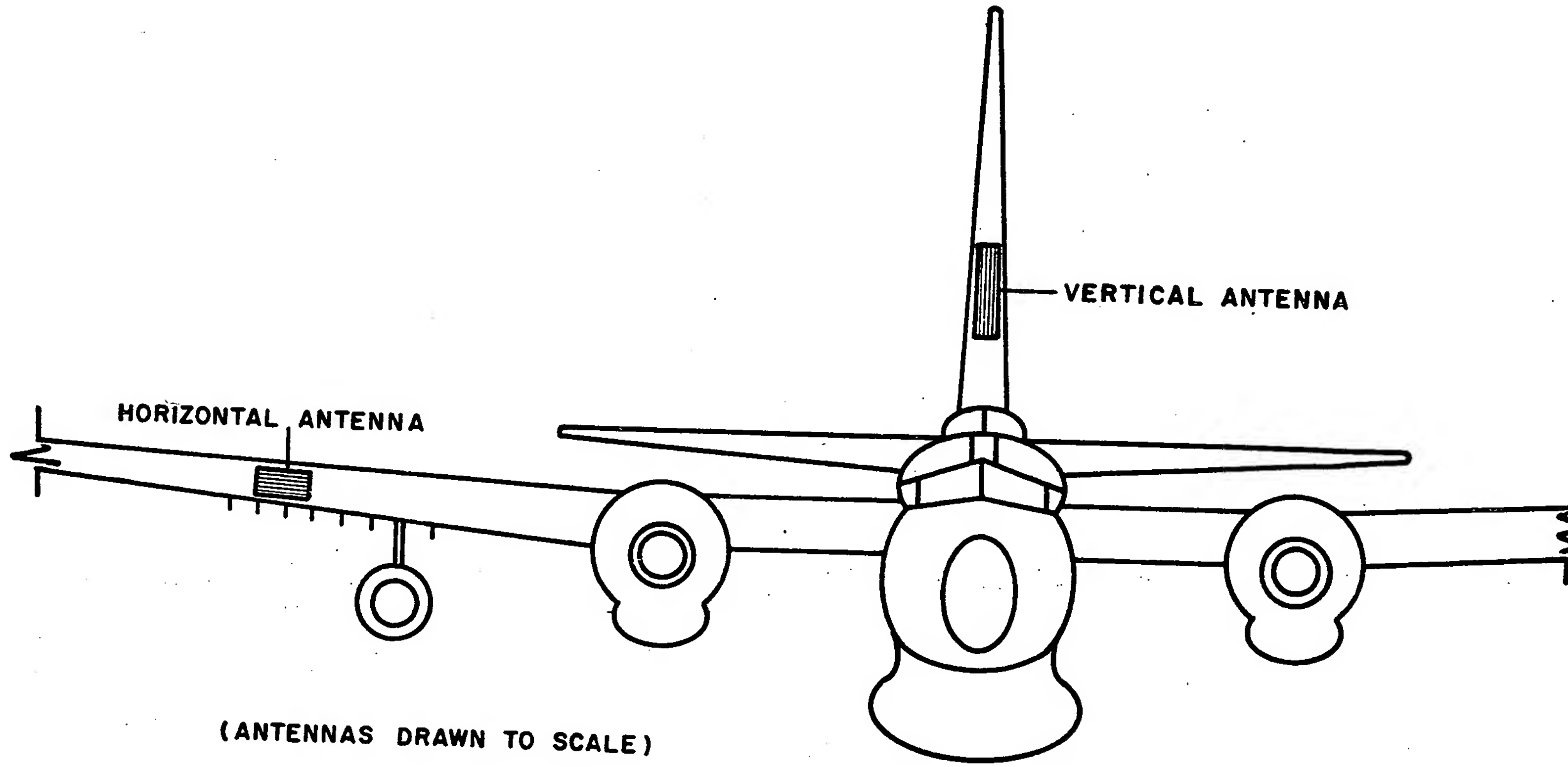

FLUSH-MOUNTED ANTENNAS

FIG. 11

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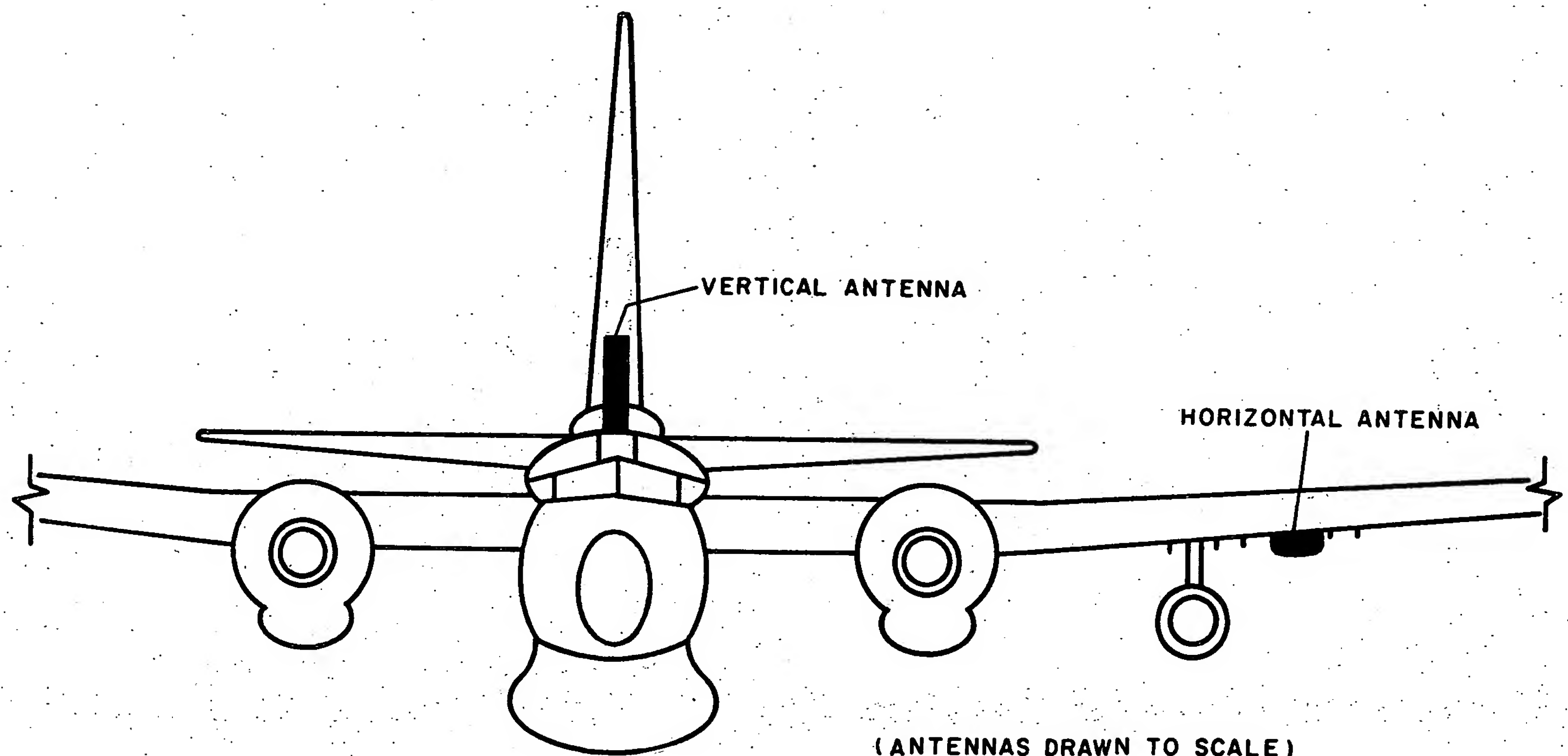

FIG. 12 - EXTERNAL MOUNTED ANTENNAS

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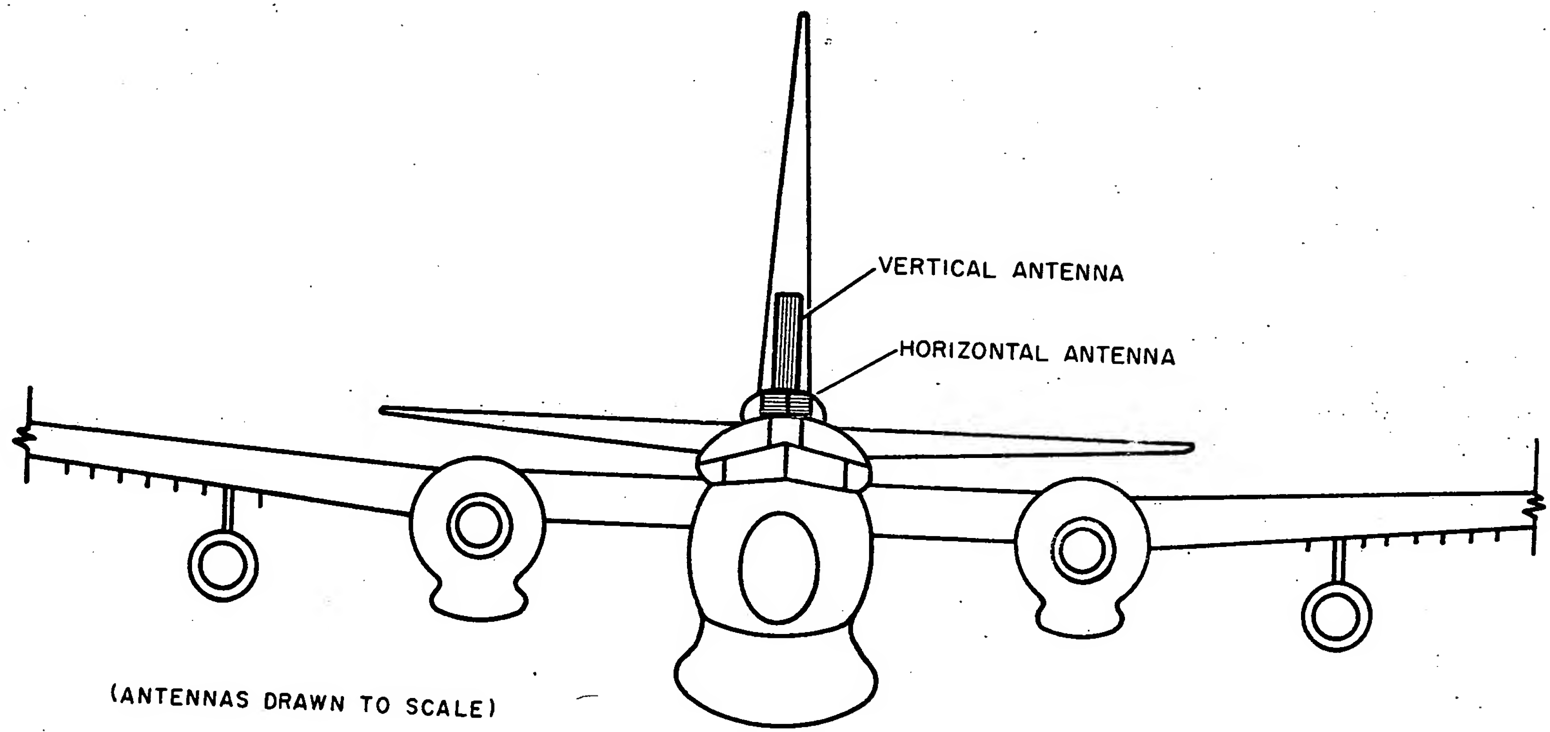

T-MOUNTING CONFIGURATION FOR ANTENNAS

FIG. 13

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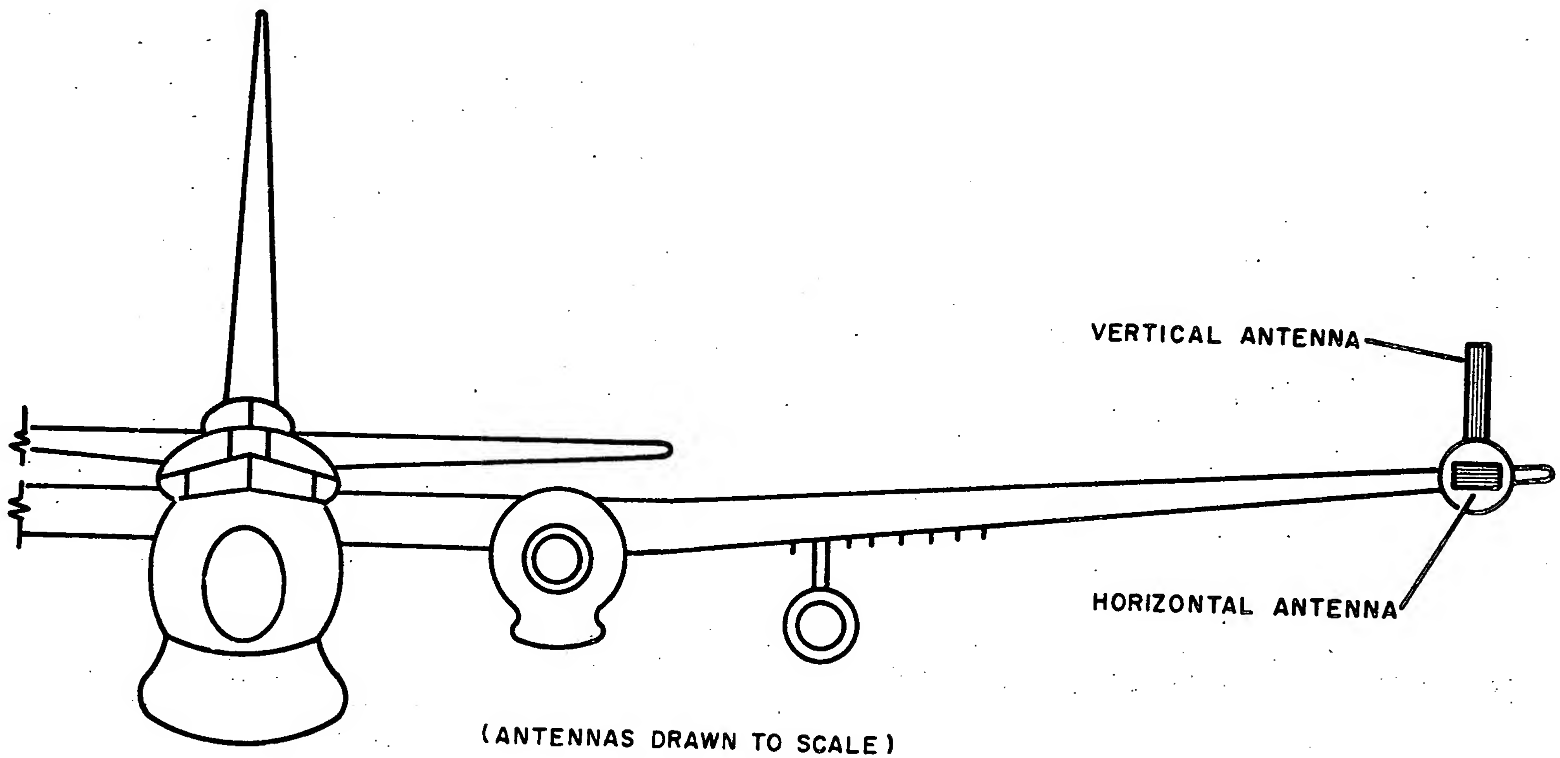

WING TANK MOUNTED ANTENNAS

FIG. 14

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problem. If the antennas are in close proximity this may be done simply with a mechanical coupling between the vertical antenna drive shaft and the horizontal antenna mount. However, it would require the use of a servo amplifier if they were separated by any distance. Either of these last two systems provide the additional advantage of installation space for many of the components required for the system.

Figure 15 is a side view of the installation illustrated in Fig. 14. This figure, though not to scale, portrays the additional advantage of providing installation space for most of the system, thus somewhat relieving the crowded condition within the balance of the airframe. The only unit requiring fuselage space would then be the indicator and its required power supply which could be mounted in any convenient location. This scheme would, in addition, reduce the required inter-cabling to a bare minimum, for the only aircraft wiring would be primary power input, and one bundle between the indicator and wing tank to carry system sync, video and antenna angle data.

Construction would be of the "barrel-type" utilized in missile guidance and fighter radar systems, offering the combined advantages or neat packaging, ready access for servicing, and easily replaceable units. This then, is the preferred system in the view of this contractor. However, should this method be ruled out for some other reason, an installation along the lines of the configurations shown in Fig. 11 through Fig. 13 is completely feasible.

There are numerous other possibilities for mounting the antennas. Some novel schemes have been demonstrated in the laboratory. Some of these schemes offer means of flush mounting linear arrays on the side and bottom surfaces of the aircraft and still retain forward viewing. If the antenna investigation show these to be practical, installation will be a minor problem.

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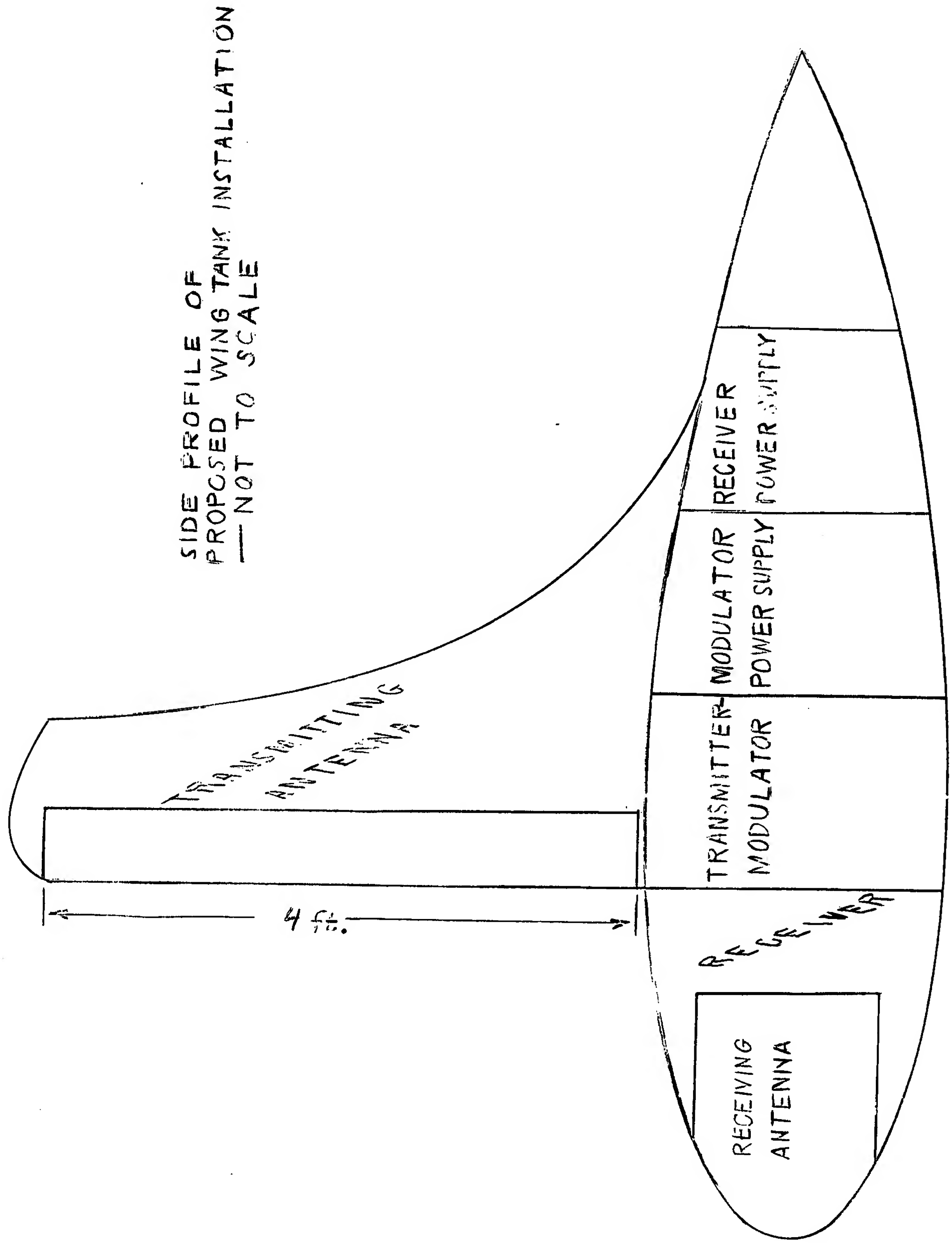

FIG. 15

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This proposal is based on the assumption that these novel schemes will not prove feasible in the time span of the development, therefore, all planning is based on conventional techniques.

VII. Breadboard Models

The entire system will be checked during the design stage by means of laboratory breadboard models. Each unit will be made up or simulated in breadboard fashion. As far as practicable the several breadboard models will be combined to obtain a composite set-up to check overall system operation, and any problems of interaction.

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VIII. Schedule and Work Plan

A. General

The program will consist of three phases. The first will be a design phase in which all parameters will be reviewed. Reference will be had to the results of flight tests on a current terrain avoidance program. (Contract AF33(616)-3248).

The second phase will consist of electrical design verification by means of laboratory breadboard set-ups of all portions of the circuitry.

The third phase will consist of design and construction of a flyable developmental model. This model will be designed and built using MIL-E-5400 as a guide only. Complete parts lists will be furnished but no formal non-standard parts and materials procedure will be used. Since a single model is being built, no destructive tests will be performed on the completed model. This proposal is based on performing the following tests only: Explosion; Temperature over the range -55°C to +55°C.; Vibration per MIL-E-5400.

The model will be built in the model shop to drawings, sketches and records of changes sufficient to permit building additional models or making up a formal set of drawings, should this be required by subsequent contracts.

The breadboard and developmental model stages will overlap to reduce the over-all elapsed time. It is anticipated that breadboard activity will be continued until the developmental model is ready for delivery.

Consideration will be given to the fact that it is planned to conduct flight tests with the developmental model installed in a government furnished aircraft. Installation may be performed by the Air Force or by West-

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inghouse under a subsequent extension of a contract to implement this proposal.

B. Delivery Schedule

The following items will be supplied:

1. Letter progress reports; - monthly.
2. Developmental model; - 13 months after contract go-ahead.
3. Set of drawings, sketches and change notices to which model was constructed.
4. Final Report.

The progress reports will fully indicate status of design and construction by means of block diagrams, schematics and pertinent technical data as a result of calculation and measurement.

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IX. Background

Under Air Force Contracts AF33(616)2248 and AF33(616)3248 considerable experience has been gained in both vertical and transverse profiling techniques. A typical vertical profile of a mountain is shown in Figure 1, while a transverse profile of flat terrain (Airport) surrounding our plant is shown in Figure 16. The group involved in the terrain avoidance programs have had several years experience working with K_a band components. This group was the first group in the country to flight test a vertical profilometer and the present XMA-1 transverse profilometer is based on experience gained with the early system.

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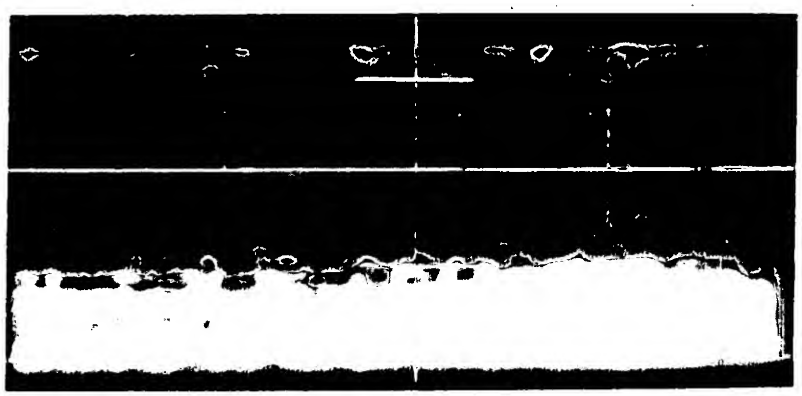
PROFILOMETER VIEW OF EDMONDS COL., N.H.

2X ANGULAR EXPANSION



TRANSVERSE PROFILE OF FLAT TERRAIN

FROM CONTRACTOR'S TEST SITE

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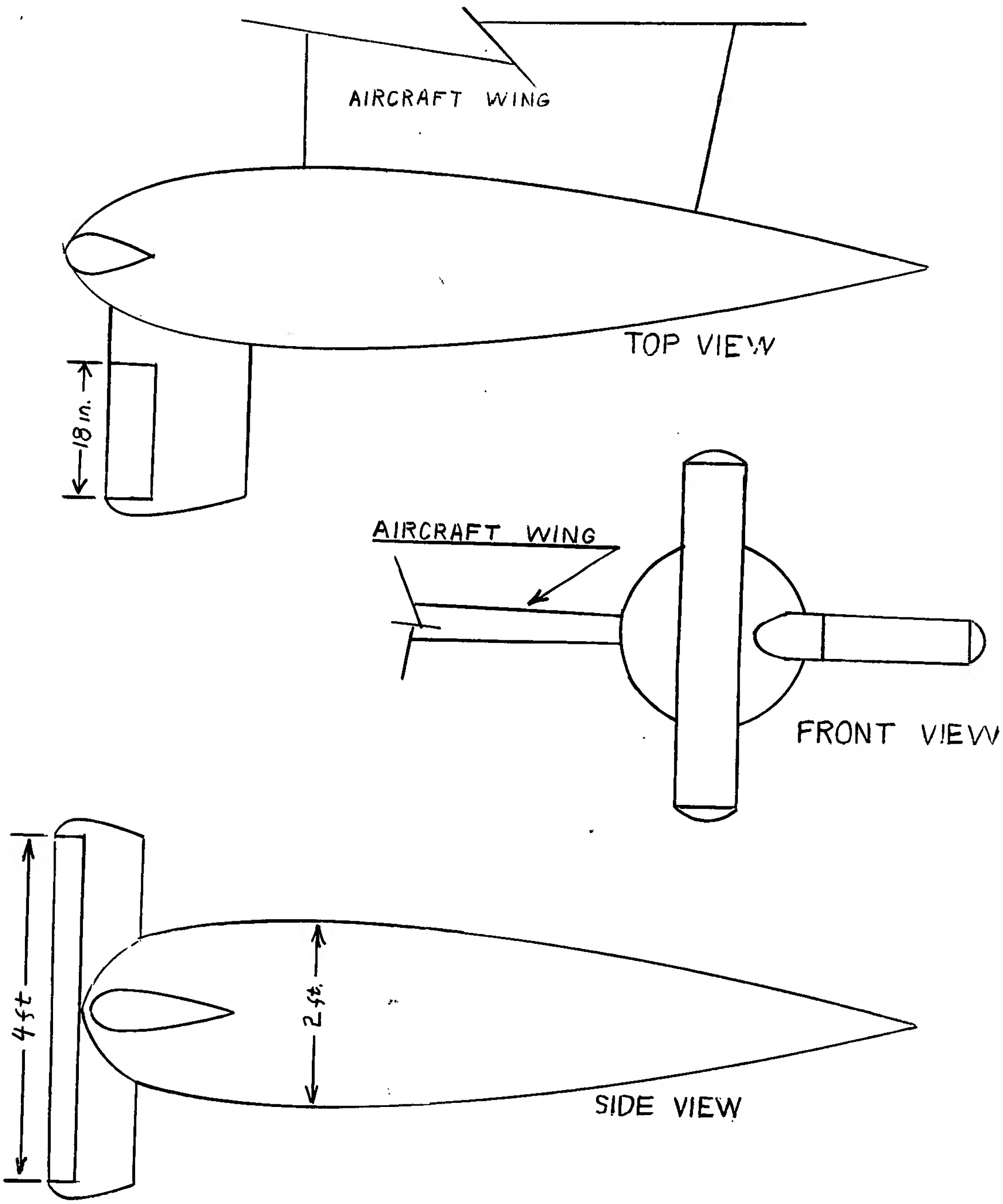

WING TANK INSTALLATION
—SYMMETRICALLY LOCATED VERTICAL ANTENNA

FIG. 15A

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